RESEARCH DEPARTMENT

U.R.S.I. SYMPOSIUM ON SPACE COMMUNICATIONS RESEARCH HELD IN PARIS, SEPTEMBER 1961

Report No. A-066

(1962/9)

THE BRITISH BROADCASTING CORPORATION
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G.J. Phillips.

G.J. Phillips, M.A., Ph.D., B.Sc., A.M.I.E.E.

(G.J. Phillips)

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March 1962

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U.R.S.I. SYMPOSIUM ON SPACE COMMUNICATIONS RESEARCH HELD IN PARIS, SEPTEMBER 1961

1. INTRODUCTION

The author attended the U.R.S.I. Symposium on Space Communications Research which was held at the Headquarters of the French Post Office in Paris from 18th - 22nd September 1961. It will be seen from the title that the emphasis was on the application of satellites in the field of communications rather than their use for fundamental scientific investigations. The programme consisted of the reading of a number of papers - some thirty in all - and a full list of these is given in the Appendix. A review of the more interesting features of these papers will be given under headings which correspond to the subject matter of each of the half-day sessions.

2. OPENING SESSION

Introductory speeches were made by the Head of the French organizing committee, by Dr. J.R. Pierce, President of the Organizing Committee, by Mr. L. Jaffe of the National Aeronautics and Space Administration, U.S.A., by Dr. Grosskopf and by Dr. R.L. Smith-Rose. Dr. Smith-Rose mentioned the formation of a new committee by the I.T.U. in 1960, namely COSPAR (Committee on Space Research). An account of the inter-relation of the various international bodies was given by this speaker during the session on frequency and propagation problems reported in Section 4. Dr. Smith-Rose finished by expressing the hope that the discussion of basic information rather than of instrumentation should be the main object of the present Symposium. The French Minister of Posts and Communications was then invited to officially declare the Symposium open. During his speech he referred to the opening in 1961 of an international centre for space research in France as an autonomous government body. A four-year plan for space research had been formulated, financed by a supplementary budget of the French P.T.T. A tracking station in Brittany would be built under the auspices of the new body. The Minister continued by welcoming co-operation with the U.S.A. and said it was an honour for France to have received the first signals from the Echo satellite across the Atlantic. He also referred to the European Space Research Organization which had been set up during 1961 and whose President, Prof. Van der Hulst, was present at the meeting. He concluded by reminding the audience that the experimental transmissions of television across the Atlantic would have a great impact on the public; it would help their appreciation of scientific work.

The chair was then taken by Dr. J.R. Pierce and the paper on scientific and research problems of satellite communication systems by H. Stanesby and F.J. Taylor of the British Post Office was presented. This paper set the scene by posing a number of questions rather than supplying information. It was concerned with the scientific and research problems of communication satellite systems, and among the items on which more information is needed are the effective noise temperature of the sky at various elevation angles and frequency, random atmospheric refraction which might destroy phase coherence, the scattering behaviour of intense ionization due to aurora and the design of very large aerials for ground stations.

3. LAUNCHING, ATTITUDE CONTROL AND TRACKING PROBLEMS

At this session, under the chairmanship of Dr. Dieminger, a total of five papers was read. From the paper by Dr. M. Rosen and Mr. V. Johnson (National Aeronautics and Space Administration) on the launching of satellites it was apparent that, of the many launching vehicles developed in the U.S.A., only two, namely the Atlas Agena-B and the Centaur, have sufficient power to provide a useful payload in a 24-hour equatorial orbit. A much larger rocket, the Saturn, will not be available for a number of years. It is partly for this reason that orbits of greatest interest at the present time for communication satellites include circular orbits of shorter periods than 24 hours and various elliptical orbits. An elliptical orbit of particular interest is one inclined at $63 \cdot 4^{\circ}$ from the equator; this is because the major axis does not rotate in the plane of the orbit as it does for other inclinations. As a result, the apogee would always occur at the same latitude and would allow a wide communication coverage with a relatively small number of satellites.

The smallest of the family of launching vehicles is the Scout, which can place 150 lb payloads in a 300 mile orbit. The most useful medium-payload vehicle is the Delta, which uses the Thor rocket as a first stage; this can put small loads (about 100 lb) into a 24-hour orbit. The Centaur, yet to be fired, will use the Atlas as a first stage, and should be able to place 8500 lb into a low orbit and a payload of perhaps 1000 lb for a communication satellite in the difficult 24-hour equatorial orbit. The second stage of the Centaur will represent the first operational rocket to use liquid hydrogen as a fuel.

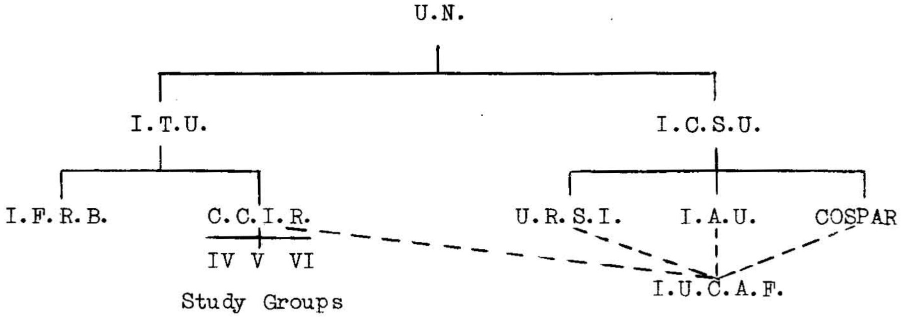
Dr. Rosen was afterwards questioned on the cost of rockets and their launching. In reply it was said that this was difficult to estimate, but the cost of the Scout rocket, including launching facilities, was in the region of $1,000,000, while the larger rockets cost some $8,000,000.

Three subsequent papers were largely concerned with theoretical considerations of the attitude stabilization of satellites. To date, most satellites have been stabilized by the spin method only, but this has limited potential because some degree of control might be needed to correct progressive drifts. It was therefore necessary to make a theoretical study of more refined methods of orienting satellites. It was the opinion of one author at least that it would ultimately be necessary to have a servo-loop type of control for all active satellites, particularly those in the 24-hour equatorial orbit. Such a system would require to sense the deviation of the attitude from the ideal, and apply a corrective torque to the vehicle or to the aerial system. The most attractive method for producing a torque would rely on the use of flywheels for fine control, supplemented by gas jets or magnetic methods. The paper by Dr. J.C. Simon made an interesting suggestion which might avoid the need for an elaborate attitude-stabilizing equipment; it suggested that the satellite should be fitted with, say, ten aerials of reasonable gain pointing in various directions and that receivers in the satellite would detect which one is receiving the ground station best. An appropriate switching device could then ensure that the same aerial is used also for transmission back to the ground. This idea could be combined with spin stabilization, in which case the aerials would be located in a plane perpendicular to the axis of spin which would in turn be arranged perpendicular to the plane of the orbit. This would be suitable for equatorial satellites.

The final paper of this session was concerned with tracking problems and with the types of ground station aerials which would be needed in typical systems.

4. FREQUENCY AND PROPAGATION PROBLEMS

The opening paper by Dr. Smith-Rose discussed in general terms the structure of the international committees which were interested in the problem of frequency allocations. The relation of these bodies is most usefully summarized by reproducing the diagram which the author drew on the board.



Glossary

U.N.	United Nations
I.T.U.	International Telecommunications Union
I.C.S.U.	International Council of Scientific Unions
I.F.R.B.	International Frequency Registration Board
C.C.I.R.	International Radio Consultative Committee
U.R.S.I.	International Scientific Radio Union
I.A.U.	International Astronomical Union
COSPAR	Committee on Space Research
I.U.C.A.F.	Inter-Union Committee on Frequency Allocations for Radio Astronomy and Space Science

The I.U.C.A.F. is a newly-formed committee (of which the speaker is the Secretary-General) which has the task of co-ordinating the requirements for frequency channels, and the protection thereof, for radio-astronomy and space science, and is to participate in the work of both the C.C.I.R. and the I.C.S.U.

The remaining papers of this session covered various aspects of propagation or interference in satellite communications. It seemed likely that such effects as scintallation or refraction in the earth's atmosphere or ionosphere would not be serious at frequencies above 1000 Mc/s. On the other hand, the influence of oxygen (which has an absorption peak at 60 Gc/s) and of other constituents of the atmosphere prevents the use of very high frequencies. In fact, if the effect of rain and other forms of precipitation is considered, frequencies above 10 Gc/s can be seriously affected.

One aspect of the absorption in the earth's atmosphere (either by gases or by rain, fog, etc.) which must be borne in mind, is the serious increase in the apparent sky temperature. For example, if the **absorption** were 3 dB the effective temperature of the aerial and receiving equipment would be raised from less than 60°K to about 180°K, so that the net deterioration in signal-to-noise ratio would not be just 3 dB due to the loss of signal, but might well be 8 dB or more. For this and other reasons it is not envisaged that satellite communication links can operate satisfactorily below about 5° above the horizon.

The paper read by Dr. Vincent (Stanford Research Institute) discussed in detail the probable interference between ground stations sharing the same frequencies. It seemed that separations of the order of 100 - 150 miles would usually suffice but it was considered important that some experimental check should be made to confirm the validity of the theoretical estimate.

5. MODULATION SYSTEMS

This session ranged over a variety of possible systems for modulation, including digital systems. The choice of modulation method depends on whether there is a need to conserve space in the frequency spectrum to the greatest possible extent, or whether it is possible to exchange bandwidth for better signal-to-noise ratio for a given transmitter power in the satellite. It was interesting to note that a straightforward frequency modulation system compared quite well with some of the more elaborate systems of modulation, and in the case of television signals probably offered the most practicable solution at the present time. Dr. J.R. Pierce of the Bell Telephone Laboratories showed some slides of television pictures in which the signal-to-noise ratio had been improved by the use of a wide-band f.m. system employing negative frequency-feedback in the receiver. The object of the feedback is to hold off the "threshold effect" in f.m., i.e. to lower the input signal level at which the noise in the deviation bandwidth is sufficient to cause a rapid deterioration of output signal-to-noise ratio. This technique can offer an advantage when the deviation range is large compared with the modulation bandwidth. Thus i.f. stages with a bandwidth only slightly in excess of twice the *modulation* bandwidth, rather than the *deviation* bandwidth, are used. The local-oscillator frequency is controlled in accordance with the output so that it tends to reduce the frequency deviation of the incoming signal when it is frequency-changed to the intermediate frequency. The threshold of such a receiver is then displaced in the direction of a lower input signal, because the noise bandwidth has been reduced to that of the i.f. channel. In practice, however, difficulties can arise at the higher modulation frequencies, and the exact theory of the operation of the feedback receiver does not seem to have yet been worked out. The experiments of the Bell Laboratories, undertaken initially with a video bandwidth of 1 Mc/s, have suggested that with 15 dB feedback and a deviation of ± 9 Mc/s, the sensitivity of the receiver is improved over that of a conventional receiver by about 6 dB. It was thought that a receiver of similar performance with all bandwidths increased by a factor of 5 could be made, and this would be suitable for television or multi-channel telephony.

Another paper, by Mr. W.L. Wright (Marconi W/T Company), compared from a theoretical standpoint the use of either f.m. or pulse code modulation for a 600 telephone channel or one television channel. He concluded that the performance of the two systems of modulation did not differ greatly and that the pulse code modulation might offer an advantage over f.m. by giving a similar performance with somewhat smaller bandwidth, e.g. 20 Mc/s against 50 Mc/s. A theoretical analysis by Dr. Ghose of E.M.I. Electronics Ltd. came more firmly to the conclusion that a digital communication system is superior to the wideband f.m. system.

In discussion on this session the feeling was that while pulse code modulation systems should achieve better signal-to-noise ratios than the f.m. system with the same power, they involved more complicated receivers and suffered from more sudden threshold effects than did f.m.

6. GROUND EQUIPMENTS

The presentation by Mr. W.K. Victor (Jet Propulsion Laboratory) included a review of costs applying to American equipment and gave, for example, a plot of the cost of aerials and their drive system against the diameter of the reflector; the best-fitting curve was $C = 5 D^{2 \cdot 7}$ where C is the cost in dollars and D the diameter in feet. In addition, it provided a useful compendium of information on the principal designs and gave examples of overall signal-to-noise ratios to be expected with various satellites and ground systems. There followed a paper by two French authors which covered various theoretical aspects of the design of large receiving aerials with "low noise" properties. It is important to reduce side lobes in the radiation pattern since they are sensitive to thermal radiation from the ground, and thus tend to degrade the signal-to-noise ratio.

Two further contributions from France were papers on somewhat specialized aspects of low-noise amplifiers and contained little of general interest.

An additional contribution was made by Mr. J. Clegg of the Australian Department of Supply, who had been asked by Dr. E.G. Bowen of the Commonwealth Scientific and Industrial Research Organization, Parkes, New South Wales, to give a general description of the new radio telescope being constructed near Sydney. It is primarily for radio-astronomy, but will also be usable for satellite communications. The project was initiated in January 1958 by engaging a London firm to produce a design with a budget of about £500,000. The design was completed in April 1959 and tenders were invited from a number of European and American firms. A German firm was awarded the main contract, although certain items were sub-contracted including the servo-control system supplied by Metropolitan-Vickers of Manchester. The project was due to be completed in September 1961 and to become operational by the end of October. The telescope employed a parabolic reflecting dish of 210 ft diameter, 40 ft less than that of Jodrell Bank. It can be used at full aperture up to a frequency of 1420 Mc/s, the beamwidth being about 12 mins. of arc. The control system enables a pointing accuracy of 1 min. of arc to be achieved. Apart from an inner portion of 27 ft radius, which is of steel plate, the reflector consists of a mesh of high-tensile steel wires with approximately 1 cm spacing between wires. The mount is basically an azimuth/elevation mount, not a polar mount, and the dish is supported by a single base tower 40 ft in diameter and 40 ft high. Rotation is achieved by rotating the aerial assembly - some 80 tons in weight - on four bogies running on a circular track at the top of the tower. The adjustment of elevation is restricted to a range from the zenith to 30° above the horizon. This was one of the compromises made in obtaining a large-diameter telescope within a limited budget. The servo-system control incorporates a precision polar mount inside the main tower, carrying a mirror. For radio-astronomy purposes the main aerial is "slaved" to the movement of the precision polar mount. The site selected for the radio telescope is a flat area well away from habitation, situated 230 miles from Sydney.

7. SATELLITE EQUIPMENTS

The session on satellite equipments was not attended. The papers in this session were mainly concerned with the testing of components for use in satellites, their probable reliability, and with photo-voltaic solar cells for the provision of power.

8. SATELLITE COMMUNICATION SYSTEMS

The papers on satellite communication systems occupied two sessions and were perhaps the most interesting of the Symposium. They described in general terms the various schemes which had been proposed and the various experiments which will be carried out in the near future.

The opening paper by Mr. L. Jaffe (National Aeronautics and Space Administration) described the part of the NASA programme concerned with communications by satellites. Both passive and active satellites continue to be of interest. Some interesting details of the successful Echo I satellite were given. The sphere was made of Mylar plastic 0·0005-in thick and was covered with a thin film (a few microns thick) of aluminium by vapour deposition. The Echo I balloon was maintained under a positive internal pressure from approximately 16 days after launching and in the initial period maintained a spherical shape; later the shape degraded slowly and it is estimated to be approximately spherical with an average diameter of about 70 ft, the surface being wrinkled, thus causing some scintillation of the reflected signal.

A successor, Echo II, is under development; it is a sphere 140 ft in diameter weighing approximately 600 lb. It will employ a laminate of aluminium foil on either side of thin Mylar sheet. This construction will be more resistant to buckling and it is hoped that the satellite can maintain a spherical shape without the need for continuously applied internal pressure. It is planned to place a sphere in an orbit of 800 miles altitude in the first half of 1962. If this is successful, further satellites will be launched in higher orbits under a project known as "Rebound". It may be possible to launch more than one satellite at a time and an attempt to launch three 100 ft balloons, using a single rocket, is expected towards the end of 1962.

Turning now to active communication satellites, two broad categories are under consideration by NASA, namely the 24-hour "stationery orbit system" requiring an altitude of approximately 22,000 miles, and lower altitude systems with approximately 6000-mile heights. The 24-hour orbit systems are difficult because of the following factors:

(1) The booster rocket which could deliver only one satellite to the 24-hour orbit could place a number of simpler and lighter satellites in the 6000-mile orbit using multiple-launch techniques.

(2) The large distance from earth to the satellite requires aerials of approximately 20 dB gain to be continuously pointing towards the earth, thus requiring an attitude control system.

(3) The time delay incurred in a 24-hour-orbit system may be a problem in two-way telephone services.

As against the three satellites which could give world-wide communication on the 24-hour system, lower-altitude systems would require a large number of satellites, but these could be simpler; they could also provide the desired characteristics of long life and reliability, not requiring period or attitude control and would be practicable at an earlier date than would the 24-hour system. The NASA programme on active satellites, therefore, has as its immediate objective experimental low-altitude active satellites. There are two major projects, "Relay", a government sponsored experimental satellite development, and project "TSX" or "Telstar", financed by the American Telephone and Telegraph Co. (A.T. & T.) and being carried out in co-operation with NASA.

Project "Relay"

The Radio Corporation of America was awarded the contract for the active "Relay" satellite. The satellite will weigh just under 100 lb and will be placed in a highly elliptical orbit inclined at 48° to the equator with an apogee height of about 3000 miles. The launching vehicle will be the Thor-Delta. Solar cells and storage batteries will provide the power, and the receiver and transmitter will use solid-state devices apart from the transmitter output stage which is a 10W travelling-wave tube. Frequencies will be about 2000 Mc/s for the ground-to-satellite path and about 4000 Mc/s for the satellite-to-ground path. Two complete transponders will be carried in the satellite. The first satellite is due to be launched mid-1962.

Ground facilities include the A.T. & T. 60 ft horn aerial at Rumford, Maine, and the International Telephone and Telegraph 40 ft parabolic reflector system at Nutley, New Jersey. A number of other countries are participating in the tests, including the U.K., France, and probably West Germany, Italy and Brazil. Not the least important part of project "Relay" will be measurement of cosmic radiation experienced by the satellite and the observation of any influence they may have on the solar cells and other equipment carried in the satellite.

Project "TSX"

This project is similar to project "Relay" but will employ satellite equipment produced by A. T. & T., who have undertaken to reimburse the U.S. government for the costs of launching. One difference is that 6000 Mc/s will be used for the ground-to-satellite path in place of 2000 Mc/s used by the "Relay" satellites. The same countries have been invited to participate as for project "Relay" as the ground facilities become available.

A long-term NASA project known as "Syncom" is being arranged to launch a 24-hour orbit satellite using a Thor-Delta rocket. The satellite will weigh 135 lb and will be launched initially into an elliptical orbit with an apogee of 22,300 miles. The rocket will be re-ignited by ground control to correct the orbit into the 24-hour circular orbit when the apogee is reached. The orbit will be inclined 33° to the equator and the electronic equipment, totalling 57 lb net weight, will include a 2W travelling-wave tube transmitting 2000 Mc/s from satellite to ground. The ground-to-satellite link will be at 800 Mc/s. The axis of the satellite will be spin stabilized and control of both attitude and orbital period will be arranged, using pulsed jets; the geometrical configuration was not made clear by the speaker.

The following paper, by Mr. R.P. Havilland (General Electric, U.S.A.), reviewed the advantages of a satellite system of medium altitude (6,000 miles), which included the facilities of attitude control and station keeping (orbital period control); the satellites of this system would employ the equatorial orbit. The speaker felt that a system of this kind represents the best compromise for a world-wide communication system with principal emphasis on the telephone traffic. World-wide coverage between latitudes 63°N and 63°S is possible with ten equatorial satellites.

Mr. Havilland mentioned the probable methods to be used for attitude control. He envisaged suitable infra-red detectors which could sense the horizon of the earth or solar radiation and that attitude control would be achieved by stored cold nitrogen with suitable regulators and jet orientation to correct for large errors, while small errors could be corrected by what he called a "momentum package" containing flywheels. A possible form of flywheel might be a metallic liquid maintained in rotation by an electrical pump. A novel suggestion made by this speaker was that of using frequency modulation with frequency multiplication at the satellite so that the deviation might be perhaps three times greater for transmission from satellite to ground than for transmission from ground to satellite. This would give an advantage to the satellite-to-ground link, which is always the more difficult of the two.

The first session on Satellite Communication Systems closed with a paper by J.L. Glaser of Bell Telephone Laboratories which put forward the idea of a large number of low-altitude random-orbit satellites. These would be launched in orbits with heights above the earth's surface in the 2,500 to 9,000 mile range, but no means would be provided for maintaining the precise position of a satellite relative to the others in the system. Active satellites would be used, the system relying on a sufficient number of satellites so that the probability of one or more satellites being visible to the terminal stations on a given path is very high. If emphasis is placed on east-west paths there is a preference for the use of polar orbits, i.e.

orbits inclined at 90° in the equatorial plane. For example, the Atlantic path could be covered by 27 satellites launched in an 11,000 km circular orbit and would give a 99·9% service. A single failure in a system of this type has only a small effect on the percentage service. Only 20 satellites, which might be a commercial proposition, would still provide over a 99% reliability.

Quite a lively discussion was stimulated by these three papers; Dr. Jaffe was questioned on the present shape of Echo I satellite. In reply he said that the only information they had to go on was that the mean signal level was 3 dB below that expected for a 100 ft sphere, although shortly after launching the signal strength had agreed closely with theoretical predictions. Moreover, there are at present non-periodic fluctuations of about ± 2 dB with very occasional drops of 15 to 20 dB. It was from these observations that it had been deduced that Echo I was still at least approximately a sphere with an average diameter somewhat smaller than 100 ft; creases or wrinkles in the surface would account for the fading.

A French speaker asked if satellites at an altitude of 6,000 miles might not be rapidly destroyed by one of the Van Allen belts of trapped particles. In reply Mr. Havilland thought that this was not a serious problem provided that suitable orbits were chosen. The most serious hazard was the presence of high-speed protons which might be trapped for as long as ten years in these belts. He put forward the view that a large object in the belt could largely drain the belt of protons in a period of about a month; a number of satellites of practicable size could, he estimated, reduce the level of protons to 1% of their previous value. Regarding the higher Van Allen belt, which consisted mainly of electrons, it was more difficult to make an estimate but it might well be possible to reduce the number of electrons significantly in about a year by the launching of suitable satellites.

Mr. Turner of Hawker-Siddeley Aviation Ltd. thought Mr. Havilland had treated too lightly the problem of one satellite going out of service in his scheme. In reply, it was said that the effect would indeed be important until a replacement could be launched, but alternative routes could be used, if necessary, with auxiliary ground relays. This type of re-routing might eventually become automatic and controlled by a computer.

Dr. Glaser was questioned by the Chairman, Mr. R. Sueur, on the problem of side-lobes of large receiving aerials on the ground and the limitation imposed on the elevation angle by the thermal noise pick-up from the ground. In reply, Dr. Glaser said that his company had used horn reflectors in their experimental work because they had the minimum "spill-over" outside the main beam. The conventional parabolic reflector was relatively poor in this respect but a compromise solution with reasonable performance was offered by the "Cassegrain" feed system which uses a small subsidiary reflector at the centre of a large reflector.

The subject of Satellite Communication Systems was continued in the session held on the following day. Dr. S.P. Brown described the "Advent" programme; this is a U.S. Army project for a 24-hour orbit communication system to satisfy world-wide military communication requirements of the U.S.A. It is planned to use three equally-spaced satellites in an equatorial orbit. Initial experiments in 1962 will launch a prototype satellite in low-altitude orbits; the next stage would probably be a 24-hour satellite positioned at a latitude of 30°W over the Atlantic Ocean. One indication of the thoroughness of this programme is the decision to construct a vacuum chamber (pressure of 10^{-9} mm of mercury) in which the satellite vehicle can be tested with simulated solar radiation. As part of the programme there will be an Advent "ship" station equipped with a 30 ft diameter reflector. By co-operation with NASA it will be possible to use the same ground equipment as "Syncom".

The next speaker, Dr. W.E. Morrow, described the somewhat controversial programme, "West Ford", for launching a large number of fine-wire dipoles to form a microwave scattering region. The object of the project is to obtain two orbital bands or rings round the earth, one in the equatorial plane and one in a polar plane. The author was with the Lincoln Laboratory of the Massachussets Institute of Technology, but the project is being operated with support from the U.S. Government through the Air Force; the permission of the U.S. Government has been given for a trial experiment in which a single dispenser containing some millions of fine wire dipoles 8 mm in length will be used.* In this initial experiment the orbit will be designed so that the perigee will gradually come down into the earth's atmosphere under the influence of solar radiation pressure, thus destroying the dipoles within a limited time from launching. The experiment would enable the possible adverse effects of orbiting dipoles on the observations of radio-astronomers to be ascertained. The speaker emphasized that even at resonance the proposed belt only absorbs 10^{-6} of incident power; it is thus very transparent and should not affect observations of radio stars etc. As a communication system the dipoles are designed to resonate at 8000 Mc/s and the terminal stations will have the aerials beamed on a portion of the ring near to the mid-point between the communicating stations.

This method of communication by the energy scattered from the dipole poses difficult problems concerning the best method of modulation. In fact, during the discussion of this paper there was some disagreement between the author and one of the questioners as to the relative importance of coherent and incoherent scatter. One contributor to the discussion reminded the audience that the New York Times had recently carried a letter from the USSR Academy protesting at the project and another radio-astronomer, Dr. J.F. Denisse of the Meudon Observatory near Paris, asked the speaker for more information because radio-astronomers were anxious to detect effects that would arise from the large concentrations of dipoles ultimately envisaged in this project. Dr. Morrow expected the tests to take place early in 1962 with a 3,700 km polar orbit. In the first forty days they expected a large density in one part of the orbit, but after this period the density would be nearly uniform in the orbit. The position in the orbit of maximum density would move round in the initial period.

Another questioner, Mr. W.K. Victor, felt that the speaker had disposed of optical- and radio-astronomy difficulties but was anxious about the possible harmful effects of radar-astronomy. Dr. Morrow said he was convinced there would be no difficulties with radar except with c.w. measurements. This was a problem with which his laboratory was itself quite concerned, since their own aerials for radio-astronomy and the West Ford project would be sited relatively closeby. They were at present constructing a 120 ft diameter 8,000 Mc/s aerial with radar facilities, the transmitting power being 100 to 300 kW; they also plan to use a sensitive receiver for experiments on temperature of the surfaces of planets. The speaker pointed out that if any effects occurred they would only be for the relatively short time when the dipole belt passed through the aerial beam.

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*Since the Symposium a first trial was made early in 1962 but appears to have been unsuccessful since a band of dipoles was not detected as expected.

A paper was presented by Dr. C.M. Crain on direct broadcasting from satellites. He was concerned only with the technical requirements for f.m. transmissions in Band II. There was no immediate prospect of a 24-hour orbit being practicable since this would require an effective radiated power towards the earth in the satellite of 40 kW to give satisfactory reception to an ordinary listener. A more practical scheme appeared to be a satellite at 5,000 miles altitude. A power of the order of 1 kW would give reasonable reception (50 $\mu V/m$) and the satellite would make four passes per day with a visibility of about two hours per pass at the equator.

9. MISCELLANEOUS PROBLEMS IN SPACE COMMUNICATIONS

The session opened with a presentation by Capt. C.F. Booth on the international planning of satellite communication systems. This was a short paper on the requirements for standardizing frequency allocations, transmission parameters and operational aspects. The provisional allocations of bands for space communications in the range 1,000 to 10,000 Mc/s were totally inadequate and it was hoped that the existing bands could be widened and that bands in the region of 4,000 and 6,000 Mc/s now used for ground links might be considered on a shared basis. Many aspects of standardization including the transmission parameters will be considered at the interim meeting of Sub-Group IV of the C.C.I.R. in Washington in March 1962, prior to the Xth Plenary Assembly of the C.C.I.R. in 1963.

There followed two papers on the economic aspects of satellite communication systems. In general, the papers were concerned with an extension of the existing telephone services, and the paper by J.R. Brinkley (Pye Radio) pointed out that the expenditure on telephone calls represented about 0·5% of the budget of commercial organizations. This could help in the prediction of requirements of rapidly-developing areas. A paper by Dr. S.R. Reiger (Rand Co.) went further into the economic aspects but did not stimulate very much discussion; Capt. Booth thought that estimates at this stage were rather speculative.

The final paper of the Symposium was by Mr. K.W. Pearson (Standard Telephone Laboratories). It discussed the controversial question of time delays in satellite links. Most attention was paid to the synchronous 24-hour orbit system because of the marginal acceptability of delays in this case. The difficulties are two-fold; firstly the effect of pure delay and secondly the effect of delayed echoes which will appear in the normal telephone circuit. This question will ultimately be resolved by the international bodies concerned but the author's amusing description of some of the difficulties that can arise are worth quoting:

"The delay between question and answer cannot be avoided and it can affect the conversation in various ways, leading to confusion in all cases. Consider for example what happens when one subscriber attempts to break into the other's speech. This is a regrettable but common habit and normally is of no consequence. However, with a long transmission time, even if subscriber A stops speaking as soon as he hears B's interruption, B will get the impression that A is ignoring his interruption and will probably stop speaking. Then, when B does hear A stop speaking and starts to talk again, A has probably resumed because he thinks that B has given up".

"Another way in which delay affects speech occurs when A stops speaking expecting B to reply, but gets apparently no reply and so resumes his speech, thereby discouraging B who **has already** started to talk. Then A hears B begin to reply and stops talking only to find that B has broken off. This start-stop procedure can go on for quite a while, with the result that the speakers are just as confused as you must be by my attempted description".

The speaker concluded that the pure delay might be acceptable with experience but that the more vital need is for better echo suppressors in the telephone system.

BRH

APPENDIX

LIST OF PAPERS FOR U.R.S.I. SYMPOSIUM

Monday September 18th, morning — Opening Session

H. Stanesby & F.J. Taylor, G.P.O., U.K., "The Scientific and Research Problems of Satellite Communications Systems".

Afternoon — Launching, Attitude Control and Tracking Problems

Dr. M. Rosen & V. Johnson, N.A.S.A., U.S.A., "Launching Satellites".

Dr. R. Roberson, U.S.A., "Attitude Control and Station Keeping".

Dr. J.C. Simon, C.S.F., France, "Un-Stabilized Satellite Radiation".

E.G.C. Burt, R.A.E., U.K., "The Influence of Cyclic Torques on the Attitude Control of Earth-Pointing Satellites".

F. Gerardin, C.F.T.H., France, "Satellite Tracking Problems".

Tuesday September 19th, morning — Frequency and Propagation Problems

Dr. R.L. Smith-Rose, U.R.S.I., U.K., "The Allocation of Radio Frequencies for Experiments in Space Communications".

Dr. K. Rawer, F.T.Z., F.D.R., "Propagation Influences in Space Communications".

Dr. W.R. Vincent, S.R.I., U.S.A., "Interference in Satellite Communication Systems".

Dr. T.F. Rogers, M.I.T., U.S.A., "Propagation Effects Important in Satellite Communications".

Afternoon — Modulation Systems in Satellite Communications

G. Battail, C.N.E.T., France, "General Comparative Study of Modulation Systems".

W.L. Wright, M.W.T., U.K., "The Choice of the Optimum Modulation Method in Active Satellite Communication Systems".

C. Cardot, C.G.E., France, "Feedback Frequency Modulation as used for Satellite Communications".

Dr. S.C. Ghose, E.M.I., U.K., "Digital Methods in Space Communications".*

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*Dr. Ghose did not attend and this paper was not read but was available in printed form.

Dr. J.R. Pierce, B.T.L., U.S.A., "Remarks on Modulation Methods for Satellite Communications".

Dr. R.C. Hansen, Aerospace, U.S.A., "Digital Modulation Techniques".

Wednesday September 20th, morning Ground Equipments

W.K. Victor, J.P.L., U.S.A., "Ground Equipments for Satellite Communications".

A. Robieux & Y. Tocque, C.G.E., France, "Theoretical Study of Low-Noise Antenna Properties".

R. Liger, S.A.T., France, "The Use of Directional Systems for Reducing the Noise Factor".

G. Broussaud, C.S.F., France, "Large Bandwidth and High Stability Maser".

Dr. S.C. Ghose, E.M.I., U.K., "The E.M.I. Cathode-Ray Tube Decoding Devices for Digital Communication Systems".*

Afternoon

Dr. I.M. Ross, B.T.L., U.S.A., "Reliable Components for Satellites".

J. Picquendar, C.F.T.H., France, "Diverse Power Systems in Satellites".

D.G. Mazur, N.A.S.A., U.S.A., "Satellite Component Problems".

F. Desvignes, L.E.P., France, "Photovoltaic Solar Cells".

Thursday, 21st September, morning Satellite Communication Systems

Dr. L. Jaffe, N.A.S.A., U.S.A., "The NASA Communication Satellite Programme".

R.P. Havilland, G.E. Co., U.S.A., "Intermediate Altitude Satellite with Station Keeping".

Dr. J.L. Glaser, B.T.L., U.S.A., "Low-Altitude Random Orbit Satellites".

Friday September 22nd, morning Satellite Communication Systems (continued)

Dr. S.P. Brown, Advent, U.S.A., "The Advent Programme".

Dr. W.E. Morrow, M.I.T., U.S.A., "Communications by Orbiting Dipoles".

Dr. C.M. Crain, Rand Co., U.S.A., "Broadcasting from Satellites".

*Dr. Ghose did not attend and this paper was not read but was available in printed form.

Afternoon

Miscellaneous Problems in Space Communications

Capt. C.F. Booth, G.P.O., U.K., "The International Planning of Satellite Communication Systems".

Dr. S.H. Reiger, Rand Co., U.S.A., "Economics of Satellite Communication Systems".

J.R. Brinkley, Pye, U.K., "The Economics of Space Communications".

K.W. Pearson, S.T.L., U.K., "Transmission Problems of Satellite Communications with Special Reference to Transmission Time".